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RESEARCH ARTICLE

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MODELLING AND FAULT PROTECTION ANALYSIS OF A DC MICROGRID USING VOLTAGE SOURCE CONVERTER AND RELAYS

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ABSTRACT

A direct current (DC) microgrid has been the preferred power system in recent years because of the system's overall efficiency. Finding a suitable protection strategy is the primary issue with DC microgrids. The most promising technology for renewable energy is photovoltaic systems. To create a DC microgrid that can function both on-grid and in island mode, the basic components are a photovoltaic (PV) system with Boost converter, a battery with Buck converter, a voltage source converter (VSC), and an AC main grid. When an issue arises with the AC main grid, a voltage source converter and several relay types, including circuit breakers, are utilized to protect the DC microgrid. The study of DC microgrid protection and its effects on other devices is the main topic of this study. Additionally, it desires to give information about their function in improving the flexibility of electrical power networks and reducing the negative consequences of overcurrent issues. MATLAB SIMULINK is used to simulate and model the PV and battery linked to the main grid with various fault kinds and by employing different overcurrent protection techniques. Their features are analysed.



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I. INTRODUCTION

The major advantages that microgrids provide to both customers and power grid operators has given rise to a recent increase in research on the topic. In basic terms, a microgrid is an integrated network of distributed power sources [1]. A microgrid's versatile and flexibility of control, which support system reliability and power quality standards, are its greatest advantages over a single-generation system [2]. Microgrids can be in two ways on-grid and off-grid. In small networks, the common system divisions are an AC bus and a DC bus. By reducing the power conversion stages between the AC and DC sides, a DC microgrid enhances efficient power transfer, and most grid-tied renewable energy systems utilize DC power for both input and output. Even though DC microgrids have numerous advantages over AC microgrids, one of the main issues in power system production is building a proper protection circuit for both big and small DC networks [3]. Nowadays, most research and studies focus on determining the most effective approaches for solving protection issues in DC networks. Because of problems of small networks bidirectional power transmission, the fault currents direction while integrating system parameters, and the distinct qualities of renewable energy supplies and their types, DC microgrid protection problems are difficult to resolve using conventional methods. There are a variety of techniques for precisely detecting faults, including the use of DC circuit breakers (CBs) for grounding and fault current determination techniques. Protection problems in DC distribution systems also come due to the absence of zero current crossing, which is typically found in AC systems. Despite major advancements, protection technologies in AC transmission and distribution systems are still essentially quite basic and manageable. Most small, distributed generation (DG) networks are based on AC systems, however compact DC networks are preferred for connecting to DC-output sources including photovoltaic (PV) systems, energy storage systems (ESS), and fuel cells. [4]. MATLAB/Simulink is used to simulate a protection analysis for a DC microgrid under several fault situations. This study examines how these conditions impact power electronic components, including the converter, voltage source converter (VSC), and power loads.

Additionally, it seeks to shed light on their function in strengthening the resilience of electrical power networks and reducing the negative consequences of overcurrent incidents. MATLAB SIMULINK is used to simulate and model the PV and battery linked to the main grid with various fault kinds and by employing different overcurrent protection techniques. Their features are then compared. The following is an overview of the DC microgrid's features:

- No synchronisation issues in DC microgrid [5].
- Transmission efficiency is high in DC microgrid due to absent of reactive components increases efficiency [6].
- DC microgrids are more stable compared to AC microgrids become it free from external effects [7].
- Skin effect losses absent in DC microgrid. It leads to less cable losses [8].
- A DC microgrid's power supply is more robust since several supplies can connect to a single bus [2].
- The primary reason for preferring DC networks is that switching losses between sources and loads are lower in systems with direct current (DC) loads than in those with an AC grid [9].
- Resources and loads are DC, which lowers heat and losses [10].
- DC microgrids have greater power transfer capabilities [11].
- DC microgrid systems are safer than AC microgrid systems [12].

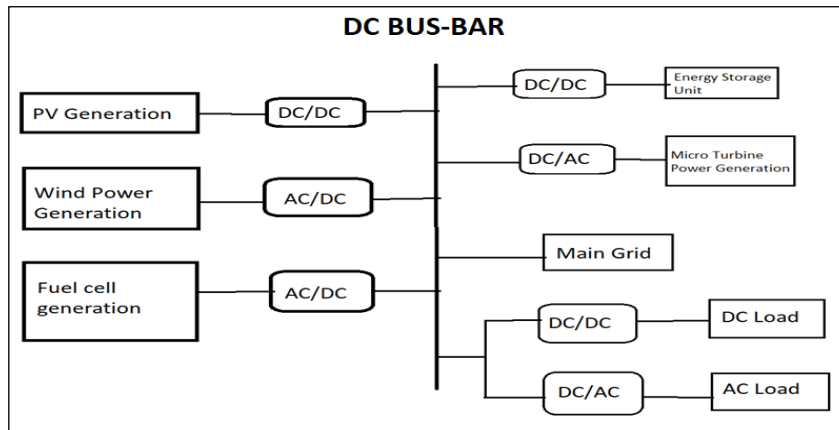


Figure 1: DC Microgrid.
Source: Authors, (2026).

II. OBJECTIVES

- DC microgrid protection and operation are often challenges with this kind of DC system.
- The DC microgrid is protected from AC side faults by a voltage source converter (VSC).
- Circuit breakers provide actual delays in the circuit, whereas relays offer a more complete protection system through recognizing more types of faults.

III. FAULT ANALYSIS FOR DC MICROGRID

For switching between AC and DC system need switching mechanism for conversion voltage source converter plays a crucial role. A Voltage Source Converter (VSC) is a power electronic converter that performs both inverter and rectifier operations. It is commonly used in grid-integrated systems, especially in DC microgrids connected to an AC main source.

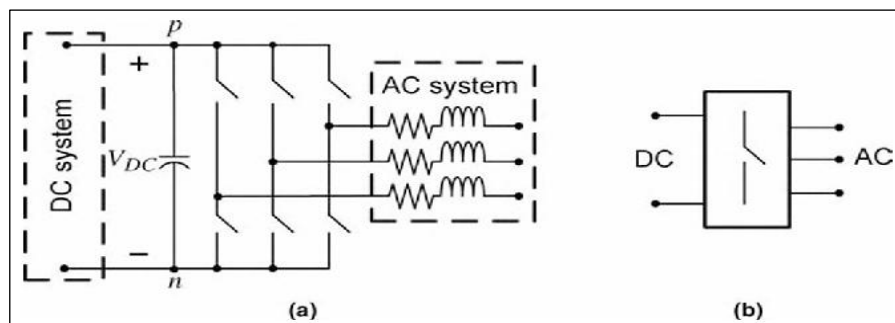


Figure 2: (a) Three-phase VSC circuit diagram, (b) VSC acts as switch between DC and AC system.
Source: Authors, (2026).

The bipolar nature of a voltage source converter's DC-side current affects its average power flow, while the DC-side voltage remains polar. Usually, the DC-side terminals of a VSC are linked in parallel with a large capacitor that functions as a voltage source.

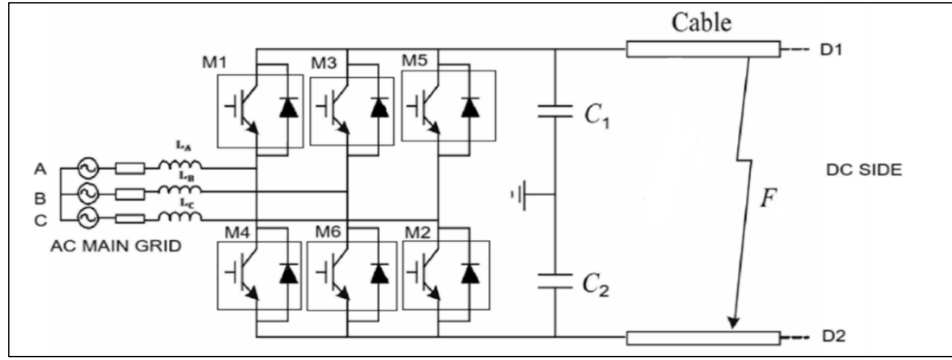


Figure 3: VSC with DC side fault.
Source: Authors, (2026).

When the DC microgrid's transmission line experiences a three-phase failure on the AC main grid, the DC side capacitor rapidly discharges from the fault point and into the AC current system. the overcurrent protection limiting the VSC, AC current still feeds the fault location through the VSC's antiparallel diode.

III.1 FAULT CONDITION

During a fault condition, three cases are observed in the Voltage Source Converter (VSC). These three cases are displayed in the circuit diagrams below.

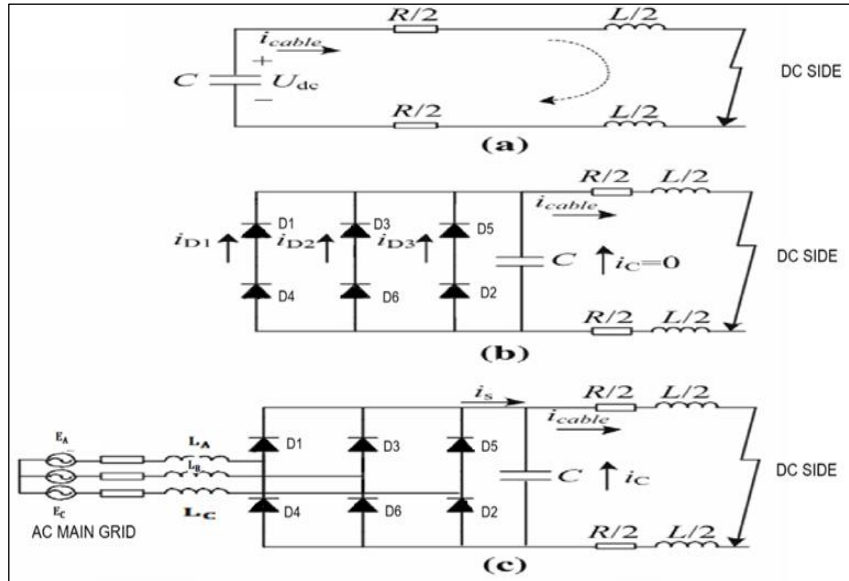


Figure 4: (a) Capacitor discharging condition during fault. (b) Diode free-wheeling action when the capacitor charge reaches. (c) AC main grid feeding.
Source: Authors, (2026).

Equations related to Voltage source converter (VSC):

$$L \frac{d^2 V_c}{dt^2} + R \frac{dV_c}{dt} + \frac{V_c}{C} = 0 \quad \dots \dots \dots (1)$$

By taking into consideration the small size the resistance is in this case,

$$\frac{1}{2}(R) < \sqrt{\frac{L}{C}} \quad \dots \dots \dots (2)$$

$$i_L = 3i_d \quad \dots \dots \dots (3)$$

III.2 FAULT CHARACTERISTICS OF VSC

The three cases above are symbolized as t_0 , t_1 , and t_2 , where:

- t_0 is the time at which the capacitor starts discharging (or the fault occurs).
- t_1 is the time at which the diode's free-wheeling action begins (or when the capacitor's current decreases to zero).
- t_2 is the time at which grid feeding starts.

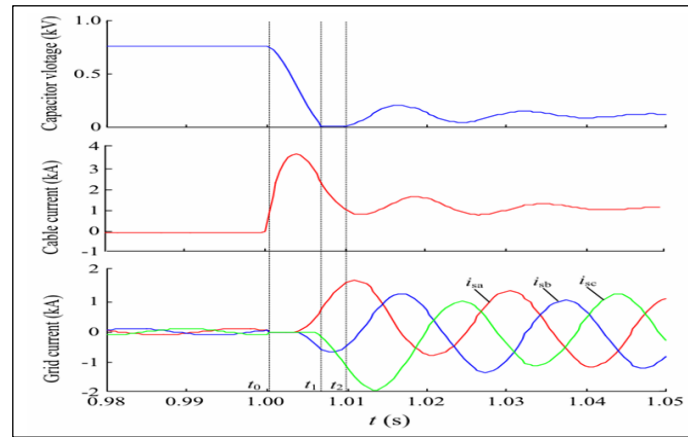


Figure 5: Fault characteristics of VSC.

Source: Authors, (2026).

The fault characteristics of the Voltage Source Converter during the t_0 , t_1 , and t_2 time intervals are shown in the waveform above.

IV. FAULT OCCURRED CONDITION

The DC microgrid transmission line fault direction is represented in the circuit below.

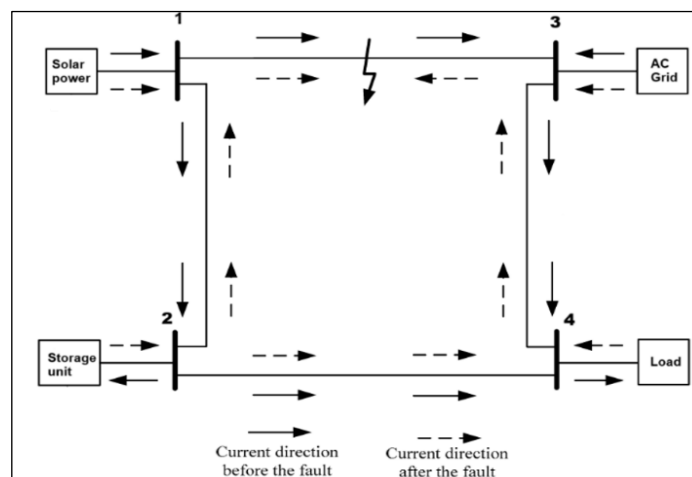


Figure 6: DC Microgrid current direction during a fault.

Source: Authors, (2026).

In the above block diagram, there are two conditions current direction before the fault condition and current direction after the fault condition.

IV.1 RELAY CHARACTERISTICS

The circuit breaker only interrupts the system while fault occurs, but relay detects the fault occurrence quickly interrupt the system by sending a signal to the circuit breaker from fault condition. There are so many types of relays based on performance operation. For Microgrid the overcurrent relays and differential relay plays a crucial role. In below tabular column discuss the comparison of overcurrent relays and differential relays.

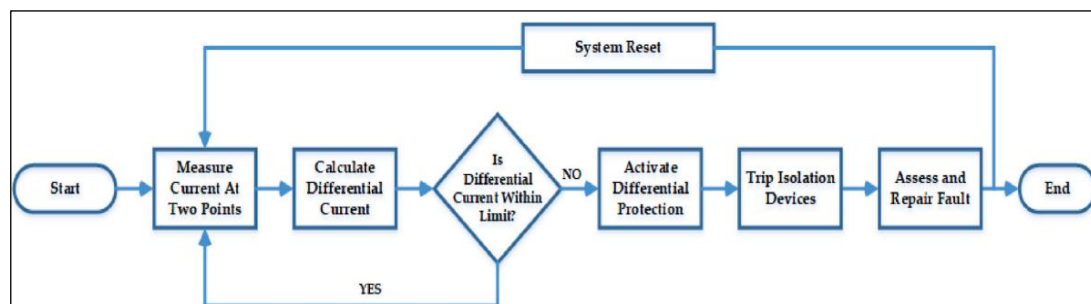


Figure 7: Flowchart of differential relay working at AC main source in DC Microgrid.

Source: Authors, (2026).

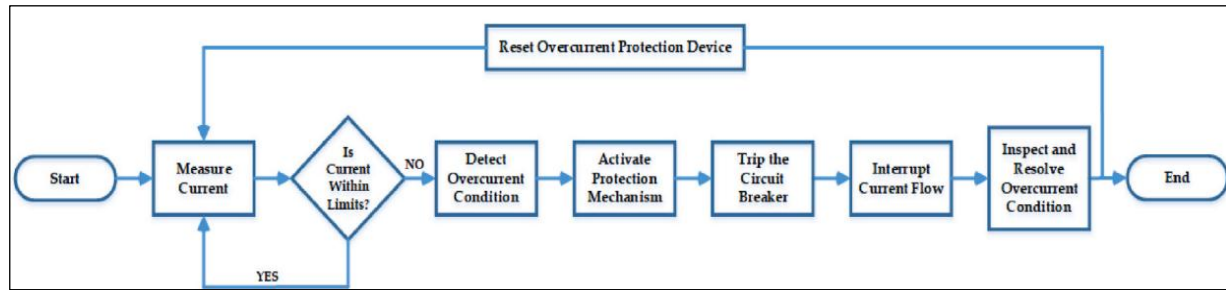


Figure 8: Flowchart of overcurrent protection device working at AC main source in DC microgrid.
Source: Authors, (2026).

Table 1: Comparing protection methods according of their Advantages and drawbacks.

Methods of protection	Advantages	Drawbacks
Over-current protection	- A basic approach - Suitable for fault interrupt techniques - Fast response to high-magnitude faults	- Less Sensitive - Requires careful time grading to prevent maloperation. - Depends on Fault Current Magnitude
Differential protection	- High selectivity and sensitivity - less dependence on fault impedance - Independent on current direction and independence with the direction of the current - Unaffected by fault resistance and a sudden rise in DC currents	- Needs regular testing and calibration for accurate performance - Requires more equipment (CTs, relays, communication) and setup effort.

Source: Authors, (2026).

Based on the operation of overcurrent relays and differential relays the performance of relays tabulated below.

Table 2: Comparison of Protection methods based on operation.

Protection Method	Speed of operation	Selectivity	Reliability	Cost
Over-current protection	Medium	Low	High	Medium
Differential protection	Very High	High	High	High

Source: Authors, (2026).

V. RESULTS AND DISCUSSION

In this paper, by comparing three relays performance individually by combining PV, Battery & AC grid at LLLG fault condition. The three relays are AC time instantaneous overcurrent relay, Differential relay, IDMT (Inverse definite minimum time) relay.

V.1 MODELLING OF AC TIME OVERCURRENT RELAY WITH MICROGRID

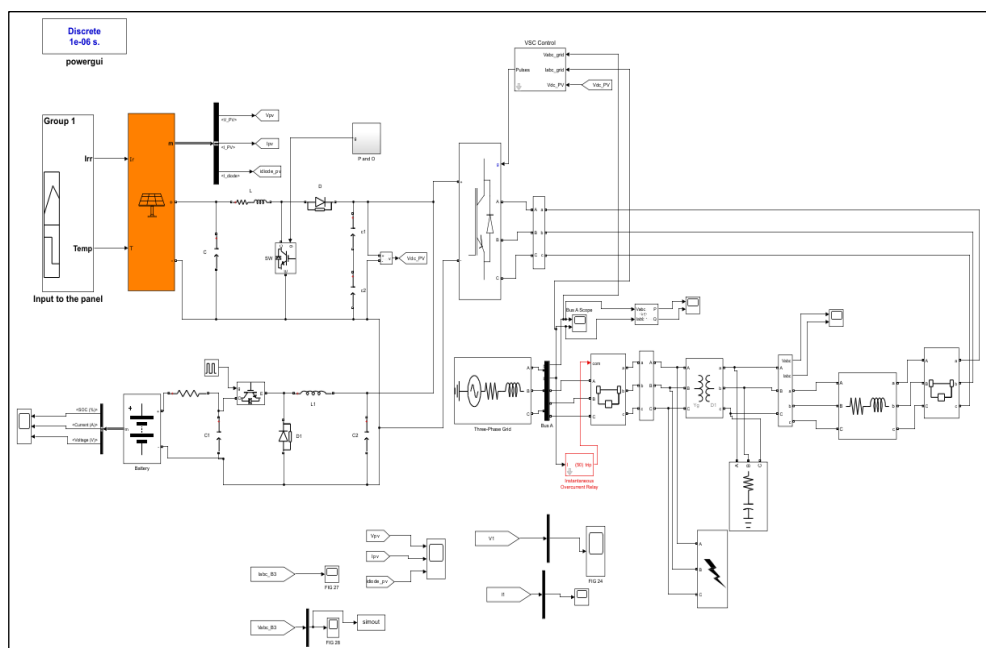


Figure 9: Simulink model design of PV with AC Main Grid, Battery and AC-time instantaneous over current relay.
Source: Authors, (2026).

V.2 MODELLING OF DIFFERENTIAL RELAY WITH MICROGRID

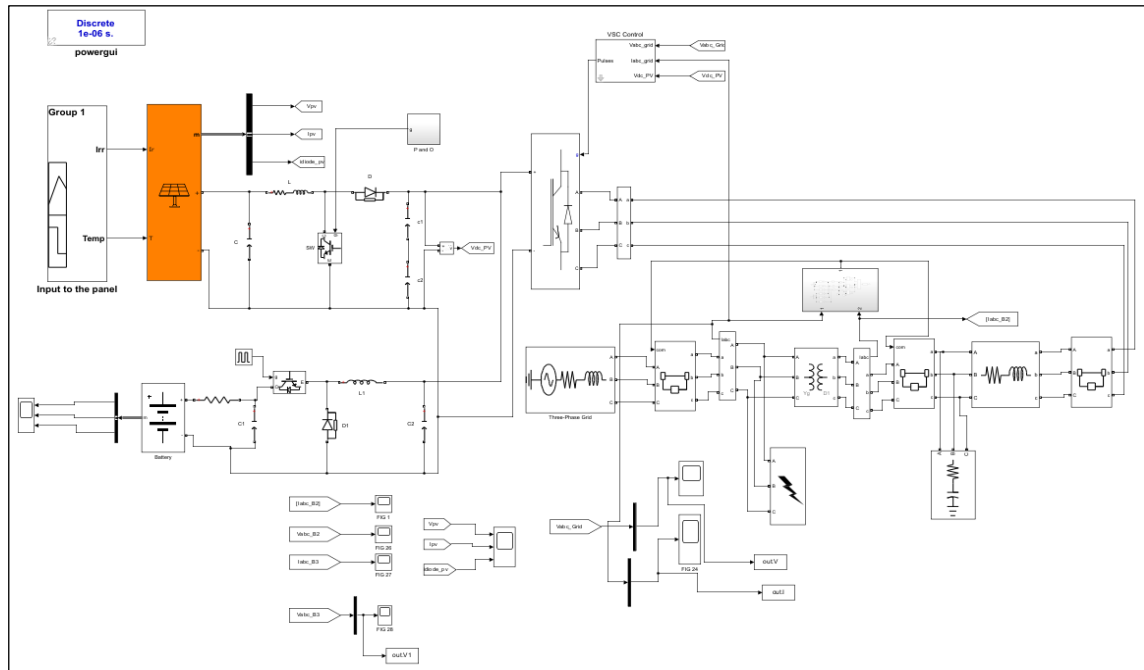


Figure 10: Simulink model design of PV with AC Main Grid, Battery and Differential relay.
Source: Authors, (2026).

V.3 MODELLING OF IDMT RELAY (INVERSE DEFINITE MINIMUM TIME) WITH MICROGRID

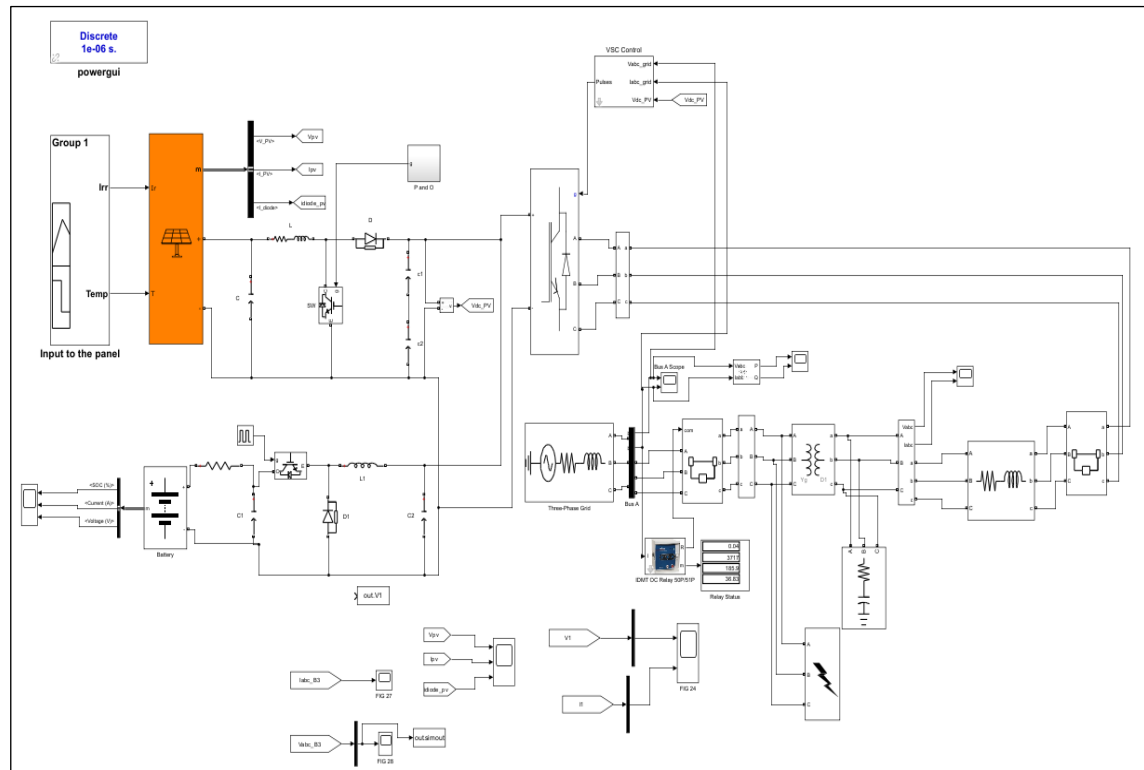


Figure 11: Simulink model design of PV with AC Main Grid, Battery and IDMT relay.
Source: Authors, (2026).

Output:

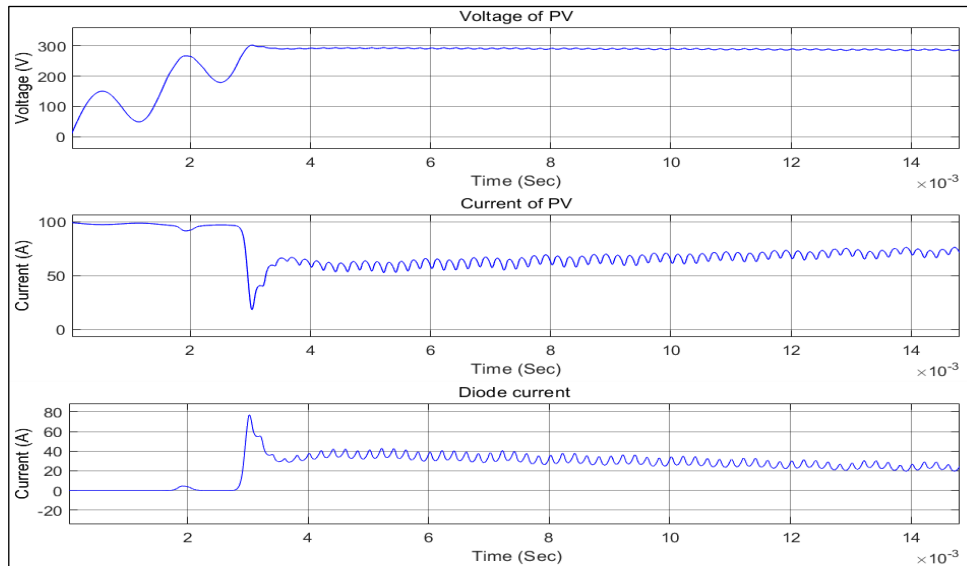


Figure 12: PV array voltage and current with diode current.

Source: Authors, (2026).

Table 3: PV module & Battery parameters.

S.No	Name of parameters	Value
1	Maximum power	305.226 W
2	Nominal voltage	1000 V
3	Rated capacity	7.2 Ah

Source: Authors, (2026).

Table 4: AC main source parameters.

S.No	Name of parameters	Value
1	Phase to phase voltage (V_{rms}) of three-phase Grid	25 KV
2	Nominal power of three-phase transformer	100 KVA
3	Active power of three phase series RLC load	10 KW
4	Nominal phase to phase voltage (V_{rms})	440 V

Source: Authors, (2026).

Output for AC time overcurrent relay:

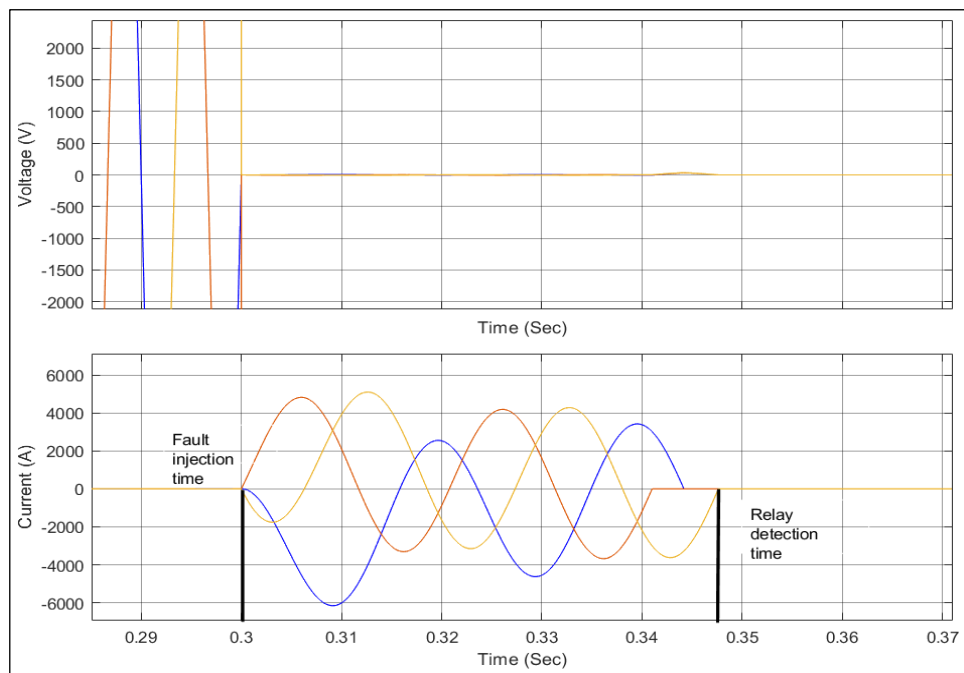


Figure 13: Current for the AC Time relay at Bus-1.

Source: Authors, (2026).

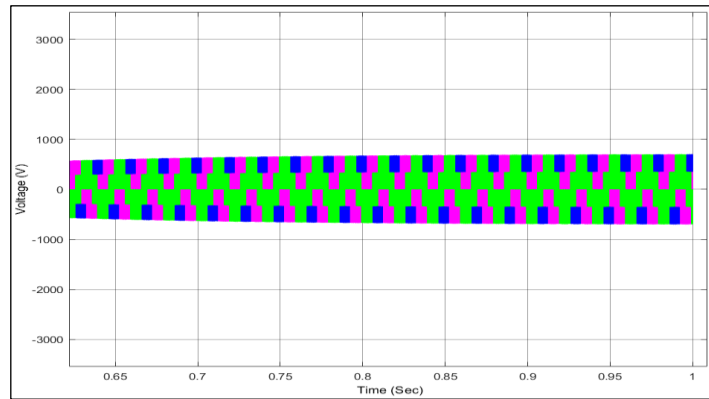


Figure 14: Voltage waveform of VSC.

Source: Authors, (2026).

The relay is set to parameters such as pickup current level and time delay settings for delay. The model includes a mechanism to simulate a three-phase fault, enabling the testing of the relay's response to severe fault conditions. Initially, the waveforms exhibit a consistent sinusoidal pattern characteristic of a stable electrical grid. At approximately 0.04 seconds, all three voltage waveforms abruptly drop to zero, which suggests that a fault condition was introduced, resulting in the complete loss of voltage. This action is indicative of a circuit breaker operation which isolates the faulted segment due to the activation of the AC time relay, hence the flat line that follows, showing the system voltage post fault and relay operation.

Output for Differential Relay:

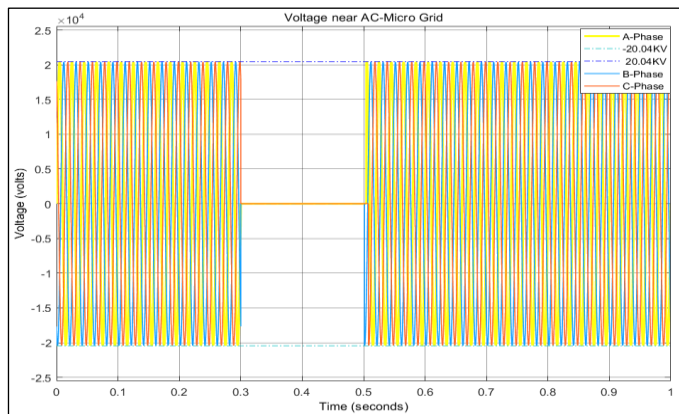


Figure 15: Voltage at Main AC grid when LLLG fault injected.

Source: Authors, (2026).

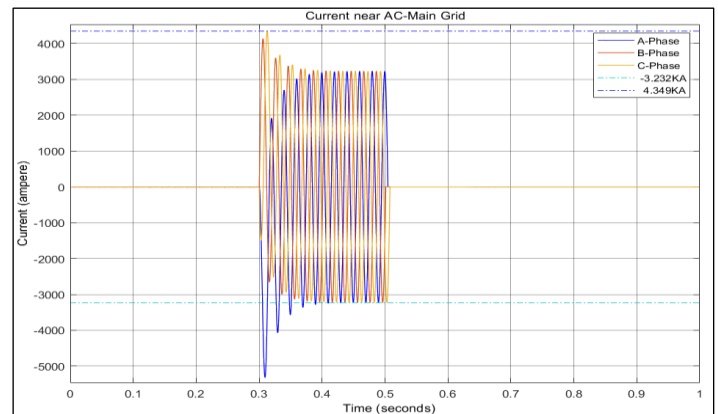


Figure 16: Current at Main AC grid when LLLG fault injected.

Source: Authors, (2026).

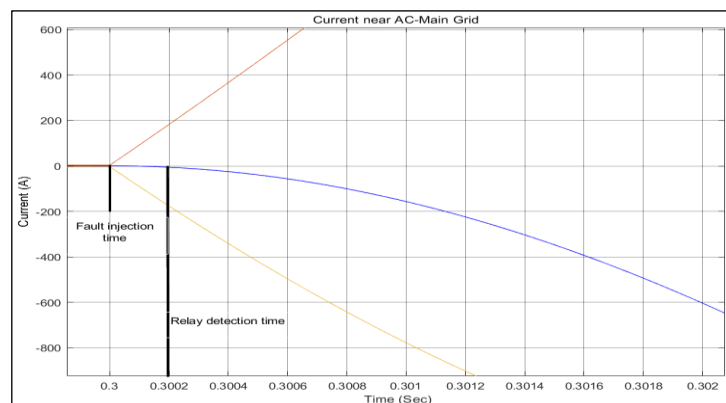


Figure 17: Operation of differential relay.

Source: Authors, (2026).

The circuit breaker, represented in Simulink as a switch block, would receive a trip signal from the transformer differential relay. To stop further damage, the switch opens according to the trip signal, isolating from protecting device from other parts of the power supply. Differential relays commonly have a restraining mechanism to prevent false tripping from quick problems like inrush currents. This is modelled using a logic block that compares the differential current against a restraint current, which is usually a function of the load current.

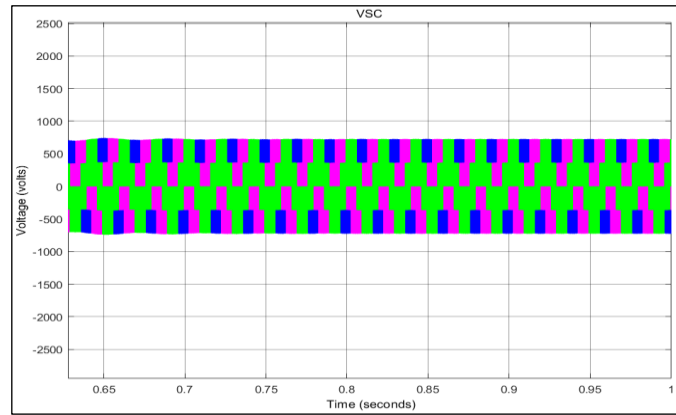


Figure 18: Voltage for VSC.
Source: Authors, (2026).

Output for IDMT Relay (Inverse Definite Minimum Time):

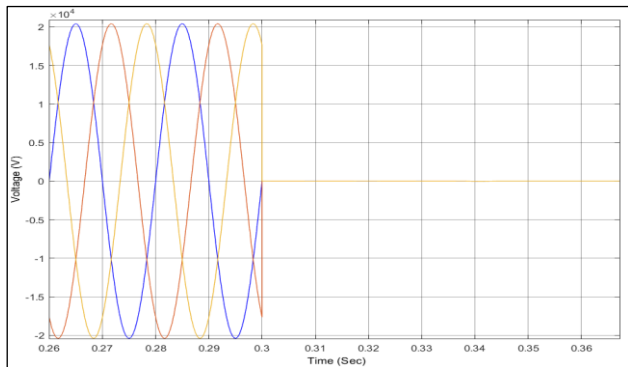


Figure 19: IDMT relay voltage at Bus-1.
Source: Authors, (2026).

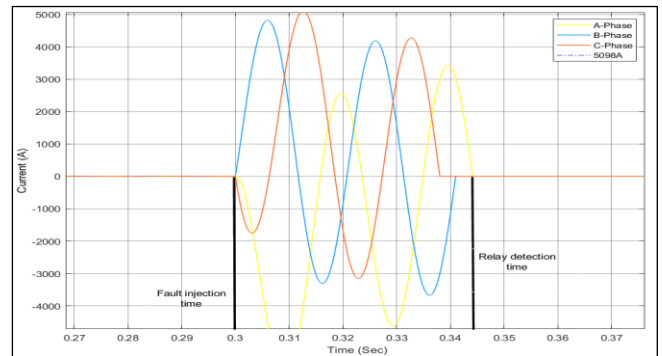


Figure 20: IDMT relay current at Bus-1.
Source: Authors, (2026).

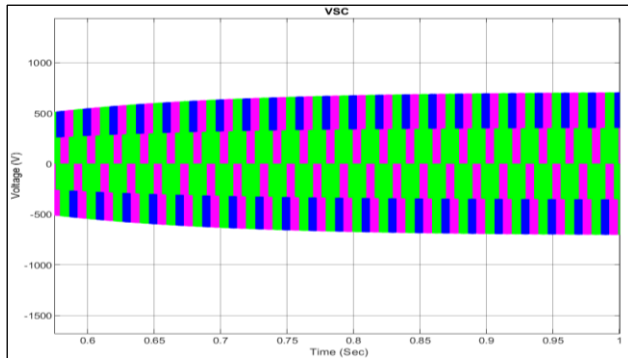


Figure 21: Voltage for VSC.
Source: Authors, (2026).

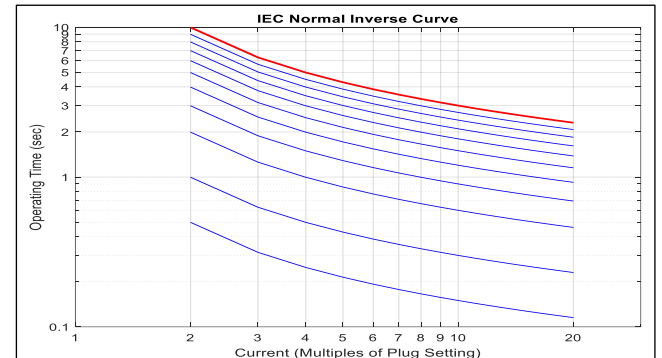


Figure 22: IEC normal inverse curve.
Source: Authors, (2026).

IDMT relay provides overcurrent protection with inverse definite minimum time characteristics. When an overcurrent situation arises, the relay block receives a signal proportional to the current from the feeder. Using the predefined settings, the relay determines whether the current is high enough and has persisted long enough to warrant a trip. The relay provides a trip signal to the circuit breaker if the current exceeds the pickup threshold and the time delay has ended (based on the IDMT characteristic). In order safeguard the equipment and maintain safety, the circuit breaker then opens to disconnect the faulted section of the system. IDMT relay operate more slowly for currents close to the threshold and more quickly for more severe currents.

Table 5: Output parameters for PV with AC Main Grid and battery.

Parameters	Values
Voltage for main grid	25 KV
Current for main grid	4.8 KA
Voltage for VSC	715 Volts

Source: Authors, (2026).

Table 6: comparison of Response time of relays.

Relay Type	Fault injection time (s)	Detection Time(s)	Response time (s)
AC time relay	0.3	0.347	0.047
Differential relay	0.3	0.3002	0.0002
IDMT relay	0.3	0.343	0.043

Source: Authors, (2026).

Differential relay has demonstrated faster response with fault detection as compared to both relays.

VI. CONCLUSION AND FUTURE SCOPE

When a fault occurs, the DC microgrid is protected using a Voltage Source Converter (VSC). Three scenarios are considered in the fault analysis study simulated using MATLAB. The critical role of overcurrent relays in safeguarding electrical systems against over current faults. The delay characteristics of various overcurrent relay has provided valuable insights into their operation and application in electrical protection systems. Differential relay has demonstrated faster response with fault detection. Through the exploration of standard time delay characteristics, inverse time delay characteristics, and other variations such as IDMT relays, a deeper understanding has been gained on of how these relays detect and respond to overcurrent conditions in electrical circuits. In further, Voltage Source Converters (VSC) could be replaced with Multilevel Converters (MLC). Currently, only overcurrent relays and differential relays are used for protection but for further, various filters and additional relays could be employed in DC microgrids to mitigate the harmonics produced by the converters.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: Ayya Chaithanya, T. Neeraja, B.Raja Sekhar Reddy, Chella Hari Prasad, and Kanna Sravanthi.

Methodology: Ayya Chaithanya, T. Neeraja, B.Raja Sekhar Reddy, Chella Hari Prasad, and Kanna Sravanthi.

Investigation: Ayya Chaithanya, T. Neeraja, B.Raja Sekhar Reddy, Chella Hari Prasad, and Kanna Sravanthi.

Discussion of results: Ayya Chaithanya, T. Neeraja, B.Raja Sekhar Reddy, Chella Hari Prasad, and Kanna Sravanthi.

Writing – Original Draft: Ayya Chaithanya, T. Neeraja, B.Raja Sekhar Reddy, Chella Hari Prasad, and Kanna Sravanthi.

Writing – Review and Editing: Ayya Chaithanya, T. Neeraja, B.Raja Sekhar Reddy, Chella Hari Prasad, and Kanna Sravanthi.

Resources: Ayya Chaithanya, T. Neeraja, B.Raja Sekhar Reddy, Chella Hari Prasad, and Kanna Sravanthi.

Supervision: Ayya Chaithanya, T. Neeraja, B.Raja Sekhar Reddy, Chella Hari Prasad, and Kanna Sravanthi.

Approval of the final text: Ayya Chaithanya, T. Neeraja, B.Raja Sekhar Reddy, Chella Hari Prasad, and Kanna Sravanthi.

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